DEVELOPMENT AND INITIAL FIELD EVALUATION OF FLIGHT DECK PROCEDURES FOR FLYING CTAS DESCENT CLEARANCES

Patricia Cashion[1], Michael Feary[1], Tsuyoshi Goka[2], Holly Graham[3], Everett Palmer[4] and Nancy Smith[1]

*Authors listed in alphabetical order

[1]San Jose State University Foundation
San Jose, California

[2]Sterling Software
Mountain View, California

[3]University of California
Davis, California

[4]NASA Ames Research Center
Moffett Field, California

ABSTRACT

The Center TRACON Automation System (CTAS) is a new computer-based system that will assist air traffic controllers in the management of arrival traffic. The Descent Advisor (DA), a major component of CTAS, uses an algorithm to predict flight trajectories and arrival times based on an aircraft's cruise airspeed, current air traffic, current atmospheric conditions, type-specific aircraft performance data and airline preferences. Controllers can use this predicted flight profile to provide a “ground-based FMS” descent clearance that will allow an aircraft to fly an efficient descent while maintaining adequate aircraft separation. New flight deck descent procedures were developed to allow commercial aircraft to comply with these CTAS descent clearances, in preparation for a field evaluation of the CTAS Descent Advisor conducted in September 1994. During this evaluation, CTAS descent clearances were issued to 97 commercial flights arriving at Denver Stapleton International Airport. Data collected to evaluate the flight deck descent procedure included questionnaire responses obtained from participating pilots, and observations recorded in the cockpit during CTAS descents. This paper describes our work on procedure and clearance phraseology development, results obtained during the September Field Evaluation, and how these results are influencing ongoing preparations for eventual CTAS deployment.

BACKGROUND

The CTAS Descent Advisor

The Center-TRACON Automation System (CTAS) is a new, computer-based support system that is being developed by NASA and the FAA to improve the efficiency of descents and to increase the rate at which aircraft land at an airport (Erzberger, 1994). One component of CTAS, the Descent Advisor (DA), provides air traffic controllers with precise descent profile and Estimated Time of Arrival (ETA) predictions similar to those provided to pilots by Flight Management Systems (Williams & Green, 1991).

The Descent Advisor, unlike conventional ATC systems, uses atmospheric modeling, current air traffic conditions, aircraft performance models, and individual airline preferences to calculate flight trajectories and predict arrival times for incoming aircraft (Williams & Green, 1991). It can also suggest different trajectories for a specific, controller-selected aircraft that facilitate the sequencing of this aircraft with other arrival traffic and optimize its fuel efficiency during descent. The controller chooses an arrival time for the aircraft and the Descent Advisor calculates a descent trajectory and descent speed that will place it at an inbound metering fix at the controller-specified time. This suggested trajectory is presented to the controller in the form of an advisory which, at the controller's discretion, is used as the basis for clearances to the aircraft. This enhances the controller’s ability to manage air traffic, allowing it to arrive safely separated and efficiently sequenced.

The September Field Evaluation

Purpose The Descent Advisor was evaluated in September 1994 at Denver's Stapleton International Airport. This initial field evaluation was conducted to evaluate the performance of the Descent Advisor, to begin development of procedures for use in compliance with DA clearances, and to determine the magnitude of errors associated with DA usage. Factors that might reduce the effectiveness of the DA are atmospheric prediction errors, aircraft performance modeling errors, radar tracking imprecision, and variations in pilot technique and clearance interpretation.

NASA Project Teams Three NASA teams worked together during this field evaluation to determine the impact of these factors on DA trajectory and arrival time estimates. The main team of researchers from Ames Research Center was concerned with evaluating the DA system performance at the Denver Air Route Traffic Control

Center (ARTCC) and with developing controller procedures for using the Descent Advisor (please see Sanford, Harwood, & Lee, in this proceedings). A second team from Langley Research Center was involved in obtaining accurate recordings of CTAS trajectories as flown by NASA's Boeing 737 aircraft. Our group, comprised of researchers from the Aviation Human Factors Branch at NASA Ames, was enlisted to develop and evaluate the DA flight deck procedures and clearance phraseology that would allow commercial aircraft to fly the DA profiles.

The goals for our project were twofold. While our immediate goal was to support the September Field evaluation, our second, longer term goal was to design and evaluate flight deck procedures, clearances and preparation material for future CTAS deployment. This paper describes our work on procedure and clearance phraseology development for the September Field Evaluation, and the results and observations obtained during the evaluation. How these results have influenced our continuing work on flight deck procedures, clearance phraseology, and pilot training material is also discussed.

FLIGHT DECK PROCEDURE DEVELOPMENT: PROJECT OVERVIEW

Descent Trajectory Requirements The trajectory provided by the Descent Advisor can be defined by a specific top-of-descent location along the flight path, a descent speed, and an altitude and speed constraint at the bottom-of-descent. The DA arrival time predictions, used by controllers to sequence arrival traffic, depend on an aircraft's actual descent path and speed closely matching this predicted trajectory.

Project Components Our primary goal was to ensure that flight crews used a descent procedure that resulted in the desired descent profile with minimal impact on the flight crews. We identified three tasks we needed to accomplish in order to meet this goal: 1) develop a minimal-training, "CTAS/DA Descent Procedure" that would produce a descent trajectory that conforms well with the DA prediction, 2) develop clear and unambiguous phraseology for the DA descent clearances that communicate the needed trajectory information, and 3) compile a briefing package to prepare flight crews for the CTAS/DA Descent Procedure and clearances. These tasks needed to be accomplished under a serious time constraint, with only two months available to develop the procedures, phraseology and briefing materials, and to obtain the needed approvals from the FAA and the participating airline.

Controller, Pilot and Airline Concerns The introduction of the Descent Advisor into the air traffic control system affects both the controller's and the flight crew's descent related tasks. A controller may clear an aircraft for a DA descent as much as 30 or 40 miles before the top-of-descent, instead of issuing the descent clearance when the controller is ready for the aircraft to descend. Controllers were concerned that once a descent clearance had been issued, aircraft might initiate their descent sooner than expected. Flight crews and airlines, on the other hand, worried that the aircraft's descent path would become more constrained, reducing the flight crew's ability to fly an efficient descent. Since a primary objective in developing the CTAS/DA Descent Procedure was to gain airline, flight crew and controller acceptance for this new air traffic control tool, we tried to identify and address the concerns of all of the affected groups. Representatives from the participating airline, the Denver ARTCC, the DA design engineers, and airline test pilots who flew simulated DA descents provided essential information about users' concerns.

Different Aircraft Types A complicating factor for development was the planned participation of different fleets of aircraft. The main difference between these fleets was the presence or absence of Flight Management System (FMS) equipment, which results in fundamentally different methods of flying and monitoring the lateral and vertical paths. The FMS-equipped aircraft were Boeing 737-300/500 and Boeing 757. The non-FMS aircraft were Boeing 737-200 and Boeing 727. One of our goals for the procedure was that it conform to pilot and airline preferred techniques for each aircraft type.

FLIGHT DECK PROCEDURES FOR CTAS DESCENTS

Non-FMS-equipped Aircraft Procedures

CTAS descent procedures were developed for the Boeing 727 for an earlier, simulator-based evaluation of the Descent Advisor (Williams & Green, 1991). These procedures provided a starting point for our Non-FMS procedure development. Minor modifications to these procedures were incorporated, then tested and approved quickly, using the Boeing 727 simulator at United Airlines Denver Training Center.

FMS-equipped Aircraft Procedures

The FMS procedures took longer to design and were iteratively modified and tested at Ames during August, 1994. Eight commercial airline pilots were recruited to fly simulated CTAS/DA descents in a Boeing 747-400 simulator, and to critique the procedure and briefing material as it was developed. This simulation testing helped to refine the CTAS/DA Descent Procedure and the field evaluation briefing material, and identified an important constraint for the clearance phraseology (discussed below).

One of the challenges in developing a descent procedure for FMS aircraft involved selection of a point to initiate the descent. The Descent Advisor's descent path calculation provides controllers with an explicit top-of-descent point. The on-board FMS, however, does not have a mechanism for incorporating an assigned top-of-descent location into its flight plan calculations; instead it determines its own top-of-descent based on programmed wind data, aircraft weight, and constraints on the descent path, including descent speed and bottom-of-descent altitude and speed restrictions. Assigning FMS aircraft a specific top-of-descent point could either rule out use of the FMS to initiate descent, or require negotiation with air traffic control about the top-of-descent location.

Since the algorithms used by the FMS and the DA for determining the flight path were similar, the two calculated top-of-descent locations should roughly coincide. The decision was made to have flight crews program the FMS with the controller issued bottom-of-descent crossing restriction and descent speed, and to use the FMS calculated top-of-descent point. We would then determine during the field evaluation whether knowledge of the DA top-of-descent alone provides controllers with adequate flight path information.

The briefing package for the DA Descent Procedure explained the specific parameters and expectations the descent had to meet. These included maintaining cruise speed until reaching the top-of-descent, descent with engines at idle and maintaining the cleared descent speed within +/- 10 knots until necessary to slow down for the crossing restriction.

Descent Procedure Clearance Phraseology

Clearances for the CTAS/DA Descent Procedure had two primary functions: 1) to request a flight crew's participation in the field evaluation, and 2) to provide the information needed to specify the descent profile, including descent speed, bottom-of-descent crossing restrictions and, for non-FMS aircraft, a top-of-descent location. Clearance phraseology was based on FAA air traffic control procedure document 7110.65, with changes for usability provided by CTAS engineers and a Denver ARTCC controller representative.

Three complicating factors affected clearance development. The first was the fact that aircraft participating in the field evaluation would cross three different "sector" boundaries within the Denver ARTCC air space while receiving CTAS/DA descent information. Each of these sectors is managed by a different air traffic controller, who cannot issue a clearance that takes effect outside of his airspace. The second factor was the need to limit the amount of information contained in each clearance. It became clear to us during the 747-400 simulation testing that both flight crews and controllers have difficulty remembering more than 3 or 4 distinct pieces of new information when it is packaged in an unfamiliar clearance. Morrow and Rodvold (1993) report marked increases in pilot readback errors, repeat or clarification requests, and procedural deviations when the number of commands contained within a single ATC clearance are increased. Finally, there was a need to limit the number of communications between the aircraft and the controller, both because it increases pilot and controller workload and because it prevents the controller from communicating with other aircraft.

The compromise solution for the field evaluation was to break communication into three different clearances, each issued from a different air traffic control sector:

1. <u>Initial CTAS Clearance:</u> "NASA 123, expect CTAS Descent Procedure, plan to cross DRAKO at 17,000 feet and 250 knots."

Upon entering Denver ARTCC airspace an aircraft received this "heads up" clearance, issued by the first sector controller approximately 150-250 miles from Denver. This clearance alerted pilots that they would be participating in the CTAS Field evaluation, and provided them an opportunity to decline. The clearance also included information about their probable bottom-of-descent (DRAKO) crossing restrictions, needed to plan the DA descent profile.

2. <u>First Descent Clearance (non-FMS Aircraft)</u>: "NASA 123 descend and maintain FL 240. For CTAS Descent Procedure, begin descent at 71 miles from the Denver VORTAC; descend at 260 knots, if unable, advise."

<u>First Descent Clearance (FMS-equipped Aircraft)</u>: "NASA 123, descend at pilot's discretion, maintain FL 240; for CTAS Descent Procedure, descend at 260 knots; if unable advise."

This clearance assigned aircraft a descent speed and permitted them to initiate their descent. For non-FMS pilots the top-of-descent location was explicitly assigned, while FMS-equipped aircraft were cleared for a “pilot's discretion” (PD) descent, with the assumption that they would begin descent at the FMS calculated top-of-descent point. This descent clearance extended to the high altitude sector controller’s clearance limit (FL 240).

3. Continuation Clearance: "NASA 123, cross DRAKO at and maintain 17,000 feet at 250 knots, Denver altimeter is 30.05, maintain CTAS Descent Procedure."

This final clearance, issued by the low altitude sector controller, allowed the aircraft to complete the descent. It also made clear that the bottom-of-descent crossing restrictions for the CTAS/DA Descent Procedure (contained in the Initial CTAS Clearance) were now active.

Descent Procedure Briefing Package for the September Field Evaluation

Since time and resource constraints ruled out training via simulator or instructor briefings, a paper briefing package was chosen as the only effective training vehicle. This briefing package included procedure description pages with a text supplement, a cover sheet discussing the evaluation's purpose, and CTAS/DA benefits for an efficient descent. These benefits included uninterrupted descents and fewer speed changes when crossing sector boundaries. The package also contained a letter of endorsement signed by NASA, FAA and airline representatives; and a questionnaire soliciting pilot feedback.

The procedure description page needed to adequately convey information about conformance to the DA vertical path: when and where to begin the descent, how to transition from cruise speed to descent speed, the acceptable tolerance on the descent speed, and information about crossing restrictions at the bottom of the descent, including when to begin speed changes while still on the descent path. This information needed to be presented clearly enough that flight crews could successfully execute the CTAS descent immediately after reading the briefing package. In addition, sample clearances were included to prepare the crews for the type of clearances they would receive.

The questionnaire was a major index of CTAS performance and crew feedback. Additionally, an observer log was developed for NASA cockpit observers, to maintain observation data integrity, and ensure that vital pieces of information were gathered for later analysis.

THE SEPTEMBER FIELD EVALUATION

Preparation

A list of candidate flights for the September Field Evaluation was compiled based on planned entry into Denver from the northwest arrival gate (DRAKO) and planned arrival times during light traffic (no scheduled arrivals within approximately 10 minutes of the participating flight). These requirements also determined key departure airports for these flights. Briefing packages were distributed at these airports with the help of United Airlines personnel, who also helped to inform crews of the field evaluation.

Scenario

The following describes a typical scenario for participating flight crews in the September Field Evaluation. Crews were informed about the field evaluation and given the Descent Procedure Briefing Package by their flight operations manager. Upon entering Denver ARTCC airspace, air traffic control confirmed that the crew was prepared to participate in the DA field evaluation. Next the crew received the descent clearance. Flight crews on FMS-equipped aircraft entered the crossing restrictions and descent speed into the CDU, and used the FMS to initiate and fly the descent. Crews on non-FMS aircraft used the appropriate navaids to determine when they had reached the clearance-defined descent point. All crews used thrust and drag corrections when necessary to maintain the assigned descent speed and path, and continued their descent through the feeder gate and on to Denver.

During the first week of the test, NASA observers flew in the cockpit on all participating flights. After the first week it was decided that the briefing package provided flight crews with sufficient preparation for participation in the field evaluation, and many of the later flights did not have a NASA observer on board. Researchers met many of these flights in Denver to debrief the crews and to collect questionnaires and flight data information.

Results

In order to determine the success of the Descent Procedure and clearance phraseology, the questionnaire and flight observations were analyzed. By the end of the field trial, 97 aircraft had flown the CTAS Descent Procedure. Thirty-nine of these flights were accompanied by NASA cockpit observers.

Sixty-four questionnaires were collected. The questionnaire asked pilots to identify any problems with either the procedure or the briefing package, to offer suggestions for improvement, and to describe any adjustments needed to meet the assigned speed and altitude constraints. The following is a summary of the questionnaire results.

Approximately 95% of pilots answered “no” to the question: "Was the clearance difficult to interpret?" Ninety-three percent stated they did not feel a time pressure in complying with the clearance, and 75% said they could have complied with less time. Among suggestions for improving the procedure or briefing material were: "less wording in the clearance", "[the package] needs to be on a [Jeppesen] plate", and "airspeed and altitudes need to be given sooner". Pilots frequently observed that "for FMS aircraft this was a routine procedure". Overall pilot reactions were very positive.

Less than 10% of pilots said they “needed to make unusual corrections to meet the constraints at the bottom-of-descent.” However, 57% of non-FMS pilots and 51% of FMS pilots responded that they needed to make either thrust or drag corrections to maintain the descent speed and profile. The needed corrections varied by aircraft type: of those who stated what kind of correction was required, 11 out of 13 FMS pilots added drag, while 8 out of 10 non-FMS pilots added thrust.

Pilots were also asked if they anticipated any problems with routinely flying this type of clearance. Some of the comments we received were: "there will be a problem in [thrust] increases due to anti-ice," "[what about] thunderstorm deviations," "the rate of descent was between 3000-4000 fpm, which can be uncomfortable."

Discussion

Pilots identified some of the important issues for CTAS that have yet to be fully resolved; for example, pilots questioned the effect of weather conditions on CTAS descent calculations. One discrepancy between the FMS and DA calculated trajectories can be attributed to the fact that CTAS has access to more current wind profile data than the FMS. To eliminate this discrepancy during the next field test, updated wind trend information will be provided to the aircraft using the Aeronautical Communication Addressing and Reporting System (ACARS). The pilot can then enter this “uplinked” information into the FMS, providing the same wind profile data to both the FMS and CTAS.

Additional weather factors include thunderstorms, turbulence and icing conditions. Thunderstorms may require lateral deviations, while turbulence may require vertical deviations; both will affect the descent trajectory calculation. If ice is encountered, thrust is increased as a consequence of providing thermal anti-ice protection. However, DA predictions are based on an idle power descent. Although this thrust increase can be accounted for in the FMS, no method exists for reliably informing the DA when thermal anti-icing is planned to be used. Thus the problem caused by icing conditions closely resembles the problem associated with winds: different information is available for the DA and FMS trajectory calculations.

The field evaluation shed light on several other issues. One procedural problem observed was pilot misunderstanding about when to perform the transition from cruise to descent airspeed. Although the procedure description instructed pilots to maintain cruise mach until reaching the top-of-descent, it did not explain when to transition to the cleared descent airspeed, which resulted in misunderstandings among some of the flight crews.

As mentioned earlier, the procedure was identified in clearances as the "CTAS Descent Procedure". This was partially in order to introduce the aviation community to the system as a whole. This caused an anticipated problem, a confusion between the acronyms: “CTAS” and “TCAS”. While no conceptual or procedural misunderstandings resulted from this confusion, the term used to identify the procedure may be changed in future field trials.

<u>FMS Aircraft</u> One important issue for controllers was giving FMS aircraft pilot's discretion (PD) descent clearances. As expected, pilots and the airline were very pleased that the procedure allowed them to use the FMS to fly the descent. Controllers, however, were uncomfortable issuing a PD descent clearance to FMS-equipped aircraft during the field evaluation, and felt that it would be impossible in moderate to heavy traffic conditions. The reason for this is that PD clearances permit the aircraft to begin descent anytime after the clearance is issued, requiring the controller to protect an extensive block of airspace.

Non-FMS Aircraft The CTAS clearance referenced the top-of-descent point for non-FMS aircraft using the Denver VOR ("...begin descent 71 miles from the Denver VORTAC"). This caused several different problems for flight crews due to the atypical nature of referencing a VOR that was not being used for navigation to determine a top-of-descent point. One example of the resulting confusion was demonstrated by a flight whose crew calculated the "along path" distance to Denver (which included a 60 degree heading change), instead of the "straight line" distance. This calculation placed the top-of-descent point roughly 10 miles late, causing the aircraft to be high on the descent path. Understandably, in response to the question about anticipated problems flying this procedure, one of the pilots replied "give us easily defined descent points."

FUTURE DIRECTIONS

Preparations are currently underway to conduct additional field evaluations of the Descent Advisor. As a result of the September Field Evaluation, the procedure, phraseology and briefing package have changed considerably. In response to pilot comments on the excessive length of the briefing package, the description pages have decreased from 6 (8.5 x 11) pages to 1 (5.5 by 8.5) page with a procedural description on the front and a description of the next field evaluation on the back. In addition, future tests will involve three airlines and a variety of both FMS, non-FMS jet aircraft and turboprop commuter aircraft, so the distribution methods used in the last test are no longer practical. To solve these problems the procedure description page will be distributed through Jeppesen or through standard company distribution routes with the rest of the crews' instrument charts.

The most significant procedural change was the decision to give FMS aircraft a controller issued top-of-descent point, as a result of controller dissatisfaction with giving FMS aircraft a pilot's discretion descent during the September Field Evaluation. Development of the new pilot procedures and phraseology is ongoing. FMS procedures are being evaluated using simulators at Ames and the United Airlines training facility. Finally, a users' committee composed of controller, airline, and pilot representatives has been formed. This committee provides a forum for these groups to express their views and plan for eventual CTAS deployment.

ACKNOWLEDGMENTS

We would like to thank Randy Kelley and John Rowbottom of United Airlines, and Jim King, a CTAS consultant at Denver ARTCC, for their generous assistance and support during the September Field Evaluation.

REFERENCES

Erzberger, H. (1994). *Concerning the Center-TRACON Automation System (CTAS).* Presented to the Federal Aviation Administration Research and Development Advisory Committe, July 12, 1994, Washington, D.C.

Morrow, D. & Rodvold, M. (1993). *The influence of ATC message length and timing on pilot communication.* (NASA Contractor Report #177621).

Sanford, B. D., Harwood, K., & Lee, K. K. (1995). Tailoring advanced technologies for air traffic control: The importance of the development process. *The Eighth International Symposium on Aviation Psychology,* Columbus, Ohio.

Williams, D. H. & Green, S. M. (1991). *Airborne four-dimensional flight management in a time-based air traffic control environment,* (NASA Technical Memorandum #4249).

Dr. Everett Palmer, NASA-Ames Research Center, Moffett Field, CA 94035-1000
415-604-6073 epalmer@mail.arc.nasa.gov
http://olias.arc.nasa.gov/~ev/Everett_Palmer/Everett_Palmer.html